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Process Planning For CNC Machining of Swedish Subcontractors – A Web Survey

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Abstract

Process planning of CNC machining is critical to ensure cost, time and quality parameters of manufacturing operations. At the heart of process planning is, typically the process planner, who must make a multitude of decisions regarding machines, cutting strategies, tools and process parameters etc. Today there are a number of different tools and methods available to aid the process planner. This paper explores today's industrial use of some of these aids and outlines potential underlying reasons for the current state. The empirical data is based on a questionnaire survey of Swedish CNC machining sub-contractors. The main conclusion is that despite a long history of development of various aids (CAD/CAM, PLM standards etc.) there is still a large proportion of the industry, which has not yet adopted these aids. By the responding companies 32% do not use any CAM system and only 2% use a PLM system. On the other side of the spectrum is a group of 25% that uses CAM in 75% or more of their planned products. The learning from this survey can be used to better understand the industrial needs and focus research and development efforts.

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Keywords: *Process planning; performance indicators; CAD; CAM; PLM*

1 Introduction and background

To better understand the current state of industry regarding process planning for CNC machining a questionnaire survey was developed and distributed to a large sample of Swedish sub contractors. This focuses on the level of digitalisation, the use of various performance indicators as well as short comings of process planning work.

Over the last centuries the maturity level of different computer aids has increased and the commercially available software to aid process planning are many. This has e.g. been manifested in the development of various CAD/CAM and PDM/PLM systems. Theodorou and Florou [1] studied the impact of advanced IT system as e.g. CAD/CAM on financial performance in the Greek industry. The results showed some ambiguities, where implementation of manufacturing IT systems rendered benefits for some companies and little impact in other companies [1].

However, no good overview of the actual industrial use of these systems is available. A few previous studies are available, but which only partly focus on process planning Korn [2], Dunn [3] Anderberg, et al. [4, 5]. This paper is therefore important, in order to raise the awareness of any possible discrepancy of the software aids available and their usage so that more effective process planning aids can be developed. To focus on sub contractors and small and medium enterprises (SMEs) is relevant since it is a large part of the machining business and which is associated with certain characteristics when it comes to the use of computer aids. Miller [6] states that this is due to limited IT resources and resources for making process improvements. Another problem identified by Denkena et al. [7] is that e.g. PLM systems mainly suit in-house mass production companies, thus excluding SME sub-contractors.

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1.1 Process planning aids

The objective of process planning aids are to enhance the performance of the planner to carry out the work needed to deliver a process plan and program to manufacture a product according to specified requirements and costs. These aids are many and can support the process planner on different levels. The aids can support in producing better machining operations, resulting in higher product quality, reduced manufacturing costs etc. or minimising the resource and time used for process planning work.

Figure 1 gives an overview of the herein regarded process planning aids. This paper uses a principal distinction between technical aids and methodological aids. The technical aids principally aim to automate planning work by replacing advanced analyses and calculation steps with algorithms. The methodological aids instead provide the individual planners with work guidelines and best practices and management as well as the planners with data on performance to better understand effects of decisions made and how improvement measures take effect etc.

2 Method description - Questionnaire development and respondent characteristics

The questionnaire survey was developed to minimize the respondents' efforts in participating, so that a larger number of companies would participate. In total the questionnaire contained 18 questions plus voluntary additional comments by the respondent. The following areas were included in the questionnaire:

- Use of digital information and computer aids;
- Use of performance measurements and standards;
- Use of environmental performance indicators;
- Deficiencies in process planning;
- Company characteristics.

The survey was distributed to 600 companies found at the Swedish sub-contractor portal www.industritorget.se and a smaller part consisted of companies, which previously had responded to other surveys by the authors. In total, 144 companies responded (response rate of 25%). The questionnaire was web-based, and each company's websites were visited to ensure that their main business was CNC machining and to retrieve appropriate respondent contact data. The survey was made available online and a link to the survey was mailed to the companies after that a suitable person had been found within the companies. Only companies with e-mail address have been approached. This may influence the survey response.

Questions referring to the extent of use were filled out by the respondent by giving a percentage value (0-100%) and other questions gave the respondent the possibility to choose between different alternatives. Hence the use of open ended questions was limited.

It is important to remember that all presented data herein are based on the perception and estimations of the responding persons in the companies. This implies that figures presented should not be considered as the absolute truth.

2.1 Characteristics of responding companies

The size of the companies that responded differs significantly, ranging between 1 and 500 employees, see Figure 2. The bulk of the companies are SMEs, where 95% are small companies (fewer than 50 employees). The rest are middle size companies (50-250 employees), except one company with 500 employees. The average size is 21 (median 10) employees. The number of persons working with process planning is reflected in the size of the company, but 70% of the companies have three or more persons working with process planning.

In the responding companies, 17% have primarily one-piece production and the majority has mixed production volumes. 27% have on average larger volumes than 100 parts/batch (based on 99 responses), see Table 1. With low series or one off production, the process planning time will constitute a larger part of the total product realisation lead time, hence stronger incitements for efficiency improvements of process planning. The product price in the companies varies between 5 SEK and 7 MSEK (based on 44 responses), and thus there is a large variation in prerequisites of the different organisations participating in the survey.

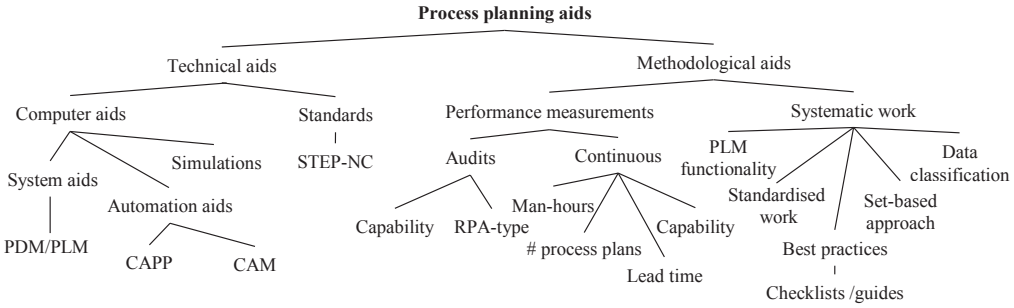

Figure 1. Overview of process planning aids [3].

Table 1. Production volumes and product value of responding companies.

		Statistic	Std. Error
Production volume for typical products	Mean	1725	1234
	Median	35	
	Std. Deviation	12280	
	Minimum	1	
	Maximum	120000	
	Valid cases	99 (69%)	
Product value [SEK] for a typical product (price to customer)	Mean	190144	1,58E5
	Median	335	
	Std. Deviation	1.05E6	
	Minimum	0	
	Maximum	7000000	
	Valid cases	44 (30%)	

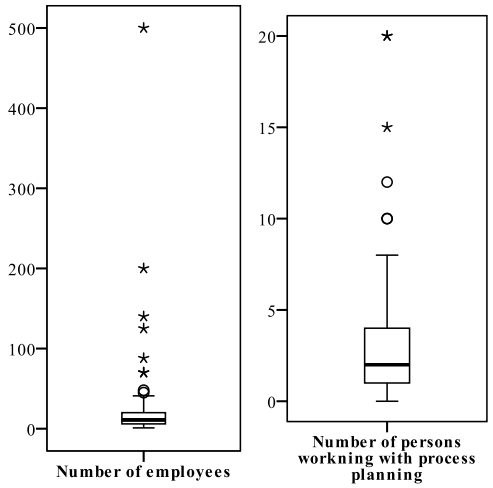

Figure 2. Boxplots of (a) number of employees and (b) number of process planners.

3 Results

Hereunder the response from all questions are reviewed. Note, that the presented bar charts, present the frequency, not the percentage.

3.1 Use of 3D models and digital data

A total of 33% of the companies do not use 3D CAD models whatsoever, and half (50%) use it in less than 10% of the cases. On the other side of the scale, there are companies that almost exclusively use 3D CAD models (Figure 3). 11% of the companies have more than 90% of their parts as 3D CAD models. On average, 30% of the industries' parts exist as 3D CAD models, although the median is only 10%, which shows the great variation between the respondents.

Having additional data (tools, machining parameters, requirements specifications etc.) stored digitally simplifies and facilitates advancements towards computer-aided process planning. As seen in Figure 4, it is common to have some digital data, but 22% of the companies still have no digital data at all. On the other end 14% of the companies have their data exclusively in digital format. It should be noted that digital data in this case does not imply that the data are stored in a database or can be seamlessly integrated in process planning work.

3.2 CAM use

In order to be able to use a modern CAM system, the use of CAD models is fundamental; it is therefore not surprising that the extent of CAM use in the responding companies resembles that of the CAD use (Figure 5). The average use of CAM is 35% and the median 12%, which is more than for the 3D CAD use. This may be explained by the use of 2D and 2.5D CAM systems that do not require 3D models. Altogether, the two situations are similar, but the use of CAM shows an even more parabola appearance than the use of 3D CAD models where 32% of the companies do not use CAM at all, whereas on the other end, there are companies which prepare the bulk of products in CAM.

Most modern CAM systems today offer some sort of automation method of CAM programming work, which often is referred to Feature-based CAM. Here the software with varying degree automatically selects machining operations depending on the identified features. By the responding companies it is only 14% that claims to use Feature-based CAM (Figure 6).

To integrating the product realisation chain has been one of the main ventures of CAD/CAM providers during the last twenty years, where various PLM solutions have been promoted. It is therefore interesting to note that only 2% of the companies use any PLM system (Figure 7).

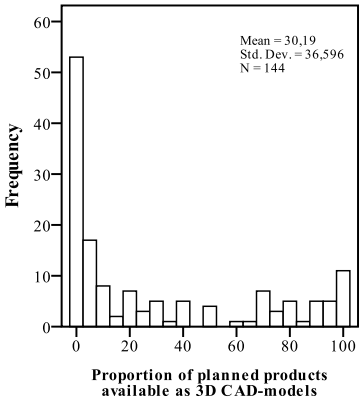

Figure 3. 3D CAD models usage.

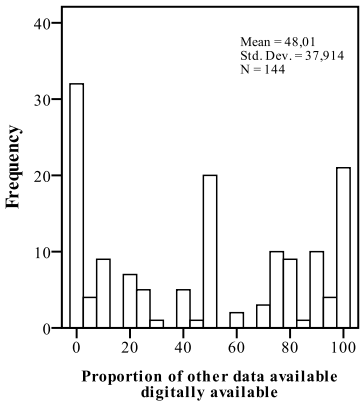

Figure 4. Other digital information usage.

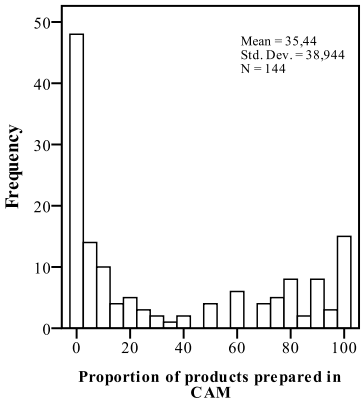

Figure 5. CAM usage.

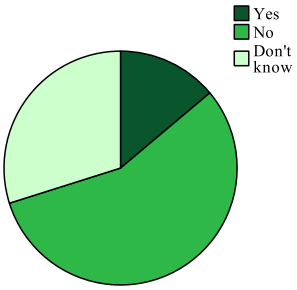

Figure 6. Use of feature-based CAM.

Figure 7. Use of PDM/PLM systems.

3.3 Use of performance indicators and measurement of process planning work

The use of methodological process planning aid was targeted with three questions in the survey. This concerned the use of performance measurements, the type of performance indicators and use of standards.

The use of performance indicators is essential to verify that actions intended to improve process planning renders the desired effects. Without any indicators and measurements of these, there are no other ways of acquiring this knowledge with the risk of no real improvement. The proportion of companies that uses any process planning performance measurements is 26% (Figure 8). Among these, 66% of the respondents use man-hours as a performance indicator. However, it is only 32% that measures the cost of process planning, which largely is the same as the total time, but which more easily can compared with other costs of operations. Production ramp-up time and quality were rated as process planning performance indicators by 40% and 47% respectively (Table 2).

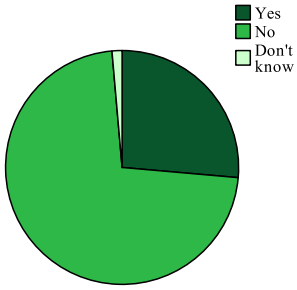

Figure 8. Use of process planning performance measurements.

Table 2. Response from companies that stated that performance measurements are used for process planning.

Performance indicators	Responses N	Percent of Cases
Process planning man-hours	25	65,8%
Number of finished process plans	3	7,9%
Process planning cost	12	31,6%
Process planning time	8	21,1%
Quality in production	18	47,4%
Ramp-up time in production	15	39,5%
Other	5	13,2%
Total	86	226,3%

In terms of enhancing quality of work and efficiency by applying more systematic process planning work, various standards can be employed to aid the creation of standardised work flows. Table 3 gives an overview of these standards and their respective usage. 42% of the companies do not use any standards, followed by 21% that use ISO 90001/4. 18% state that other standards are used. None of the responding companies use ISO 10303-238/240/242 (often referred to as STEP-NC) or ISO 22400 standard.

Table 3. Use of standards during process planning (multi choice).

Standards	Responses N	Percent of Cases
ISO 9001/4:Quality management systems - requirements	38	26.4%
ISO 14001/4/5: Environmental management systems	23	16.0%
Other standards are used	32	22.2%
No standard is used during process planning	73	50.7%
Don't know	10	6.9%
ISO 10303-238/240/242: Industrial automation systems and integration - Product data representation and exchange	0	0%
ISO 22400: Industrial automation systems and integration - Key performance indicators for manufacturing operations management	0	0%
Total	176	122.2%

3.4 Process planning challenges

With respect to deficiencies and problems identified in process planning, 43% of the companies do not experience any particular problems (In Table 4 sum of 'no problems' and 'do not know'). It is worth to note that 31% of the companies experience competence problems, although it is not stated what these problems relate to. Further studies are consequently needed to investigate whether problems concern lacking knowledge of metal cutting, software handling skills, machines or working procedures etc.

4 Factor Correlation

To analyse the relation between the responses of the numerical scale questions, a table of the Pearson product moment correlation coefficient was constructed (Table 5).

Pearson product moment correlation (r) is defined as follows in eq. 1:

$$r=\frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2]}} \quad (1)$$

where, n is the sample size, x is the individual value of the first data set and y is the individual value of the second data set. The Pearson correlation factor describes the best fit of a linear relationship between two data sets and gives a number between -1 and 1.

It is seen from the correlation analysis that use of CAM is moderately correlated to the use of 3D CAD (r = 0.569). This relation may appear trivial, but it is an important finding since it indicates that the right prerequisites, in terms of underlying modeling methods and exchange of model data must exist to be able to automate process planning work. It should be noted, however, that the causality is not given and further work is needed to verify whether it is an ambition or need (e.g. complex geometries, 5-axis machining) to use CAM that in turn creates a need to use 3D models. The other possibility would be that the availability of digital model data creates a situation where it is feasible to use CAM to close the data transfer gap. The proportion of other digital data has a less strong correlation to 3D CAD and CAM use, although still significant at the 0.05 level. Nonetheless, the advance towards increased use of computer aids in process planning depends on the level of digitalisation.

Other significant correlations, although weak, are found between the number of people involved in process planning and CAM use and between number of people and 3D CAD use. It can thus only be speculated whether CAM and 3D CAD use is a matter of organising the business to manage a larger number of people.

Table 4. Problems identified in process planning work (multiple choice).

Problems	Responses N	Percent of Cases
Deficiencies in software	26	18.1%
Deficiencies in systematic work	25	17.4%
Knowledge feedback	27	18.8%
Problem in information retrieval	18	12.5%
Deficiencies in competence	45	31.3%
Other	14	9.7%
No specific problems	48	33.3%
Don't know	14	9.7%
Total	217	150.7%

5 Discussion and conclusion

Altogether the use of 3D CAD product data can be divided into three parts: the companies with no 3D CAD usage, the companies with the bulk of products as 3D CAD models and the third category, which is between the other two, where companies appear to be flexible and situation dependent in their use of 3D CAD data. Possible underlying explanations may be the type of machines/machine controller, customers, competency, tradition and/or company culture. However, this study has not provided data to verify this. The use of process planning performance measurements is limited, where only 17% of the companies document process planning time (man-hours). The company prerequisites (i.e. company size, number of process planners, product prices and production volumes) investigated in this survey could not be correlated to the use of 3D CAD and CAM.

The survey mainly comprised of SMEs and this may to some extent explain some of the results. For example that around 30% of the companies do not use 3D CAD and CAM respectively may be a result from this, since introduction of new systems and software oftentimes is time and resource consuming and incurs high costs, in addition to the software cost alone. This is further underlined, since many of the respondents claim problems with software performance and competence.

In support of some of the findings of this survey, Swedish statistics [7] show that 28% of the manufacturing companies use automatic product data and information exchange. This indicates that there is a large proportion of the companies that so far has not adopted this technology. A survey by the Miller [2] of U.S. sub-contractors showed that only 6% of the companies had implemented PLM and 73% of the companies used 3D CAD and 46% CAM technology. Similar results was found by Dunn [3] in the Canadian manufacturing industry, where 7% used PLM systems and 72% use any of CAD/CAE/CAM system and the survey had a similar scope in

terms of industry and size of companies. Similar figures were stated by Llach Pagès et al. [9], where 73% of the responding companies of a survey of the Spanish manufacturing industry had implemented CAD. Corresponding figure for CAM was 47% [9].

Since there is only a limited amount of similar surveys published, a global comparison difficult to make. However, in relation to the above referred to studies the findings presented appear to be in line with other countries, where survey data is available. This is valid for the studies of use of industrial IT systems and process planning computer aids, whereas for the methodological aids, has been less researched, hence any comparison to other studies has not been made possible.

As the findings here and in other surveys have indicated, the implementation of industrial IT, as e.g. CAD/CAM in manufacturing companies is only partial, Hofmann and Or [10] highlighted the importance of organisational acceptance for successful adoption of Advanced Manufacturing Technology (AMT), which includes both hardware and software. In a survey it was found that 53% of the investments in AMT was successful, thus a significant part did not render the expected benefits [10].

Compared to large enterprises, SMEs in general have fewer possibilities to influence the software provider in developing functionality that is required for the current situation. Large enterprises are often seen as key customers by the software providers and thereby have more possibilities to acquire tailor made solutions and close collaborations between solution provider and manufacturing company is not uncommon.

In this perspective it is important from a research perspective, that methods and software are developed that aids the many SMEs and which can be implemented cost effectively so that the efficiency and effectiveness of process planning is enhanced.

Table 5. Correlation matrix of scale-based questions.

		Proportion of planned products available as 3D CAD models	Proportion of products prepared in CAM	Proportion of other data available digitally available	Product value [SEK] for a typical product (price to customer)	Production volume for typical products	Number of employees	Number of persons working with process planning
Proportion of planned products available as 3D CAD models	Pearson r	1	,569**	,329**	-,092	,070	,066	,223*
	N	144	144	144	44	99	140	132
Proportion of products prepared in CAM	Pearson r	,569**	1	,299**	-,114	,065	,107	,319**
	N	144	144	144	44	99	140	132
Proportion of other data available digitally available	Pearson r	,329**	,299**	1	-,228	-,003	,165	,147
	N	144	144	144	44	99	140	132
Product value [SEK] for a typical product (price to customer)	Pearson r	-,092	-,114	-,228	1	-,047	-,078	-,112
	N	44	44	44	44	43	43	41
Production volume for typical products	Pearson r	,070	,065	-,003	-,047	1	,052	,005
	N	99	99	99	43	99	98	95
Number of employees	Pearson r	,066	,107	,165	-,078	,052	1	,231**
	N	140	140	140	43	98	140	131
Number of persons working with process planning	Pearson r	,223*	,319**	,147	-,112	,005	,231**	1
	N	132	132	132	41	95	131	132

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

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